Operational Concepts and Challenges for Optical Communications in NASA's Deep Space Network

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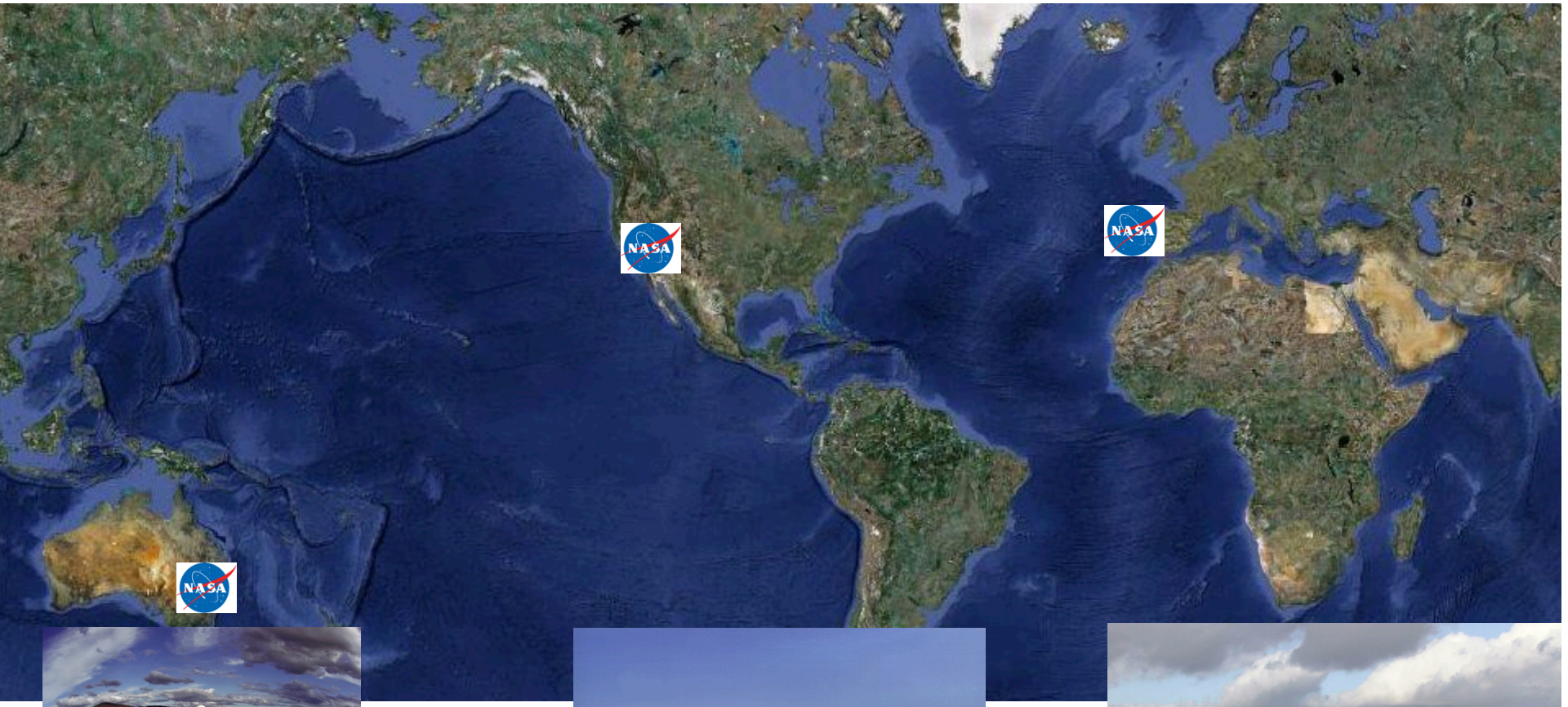
NASA Deep Space Network (DSN)



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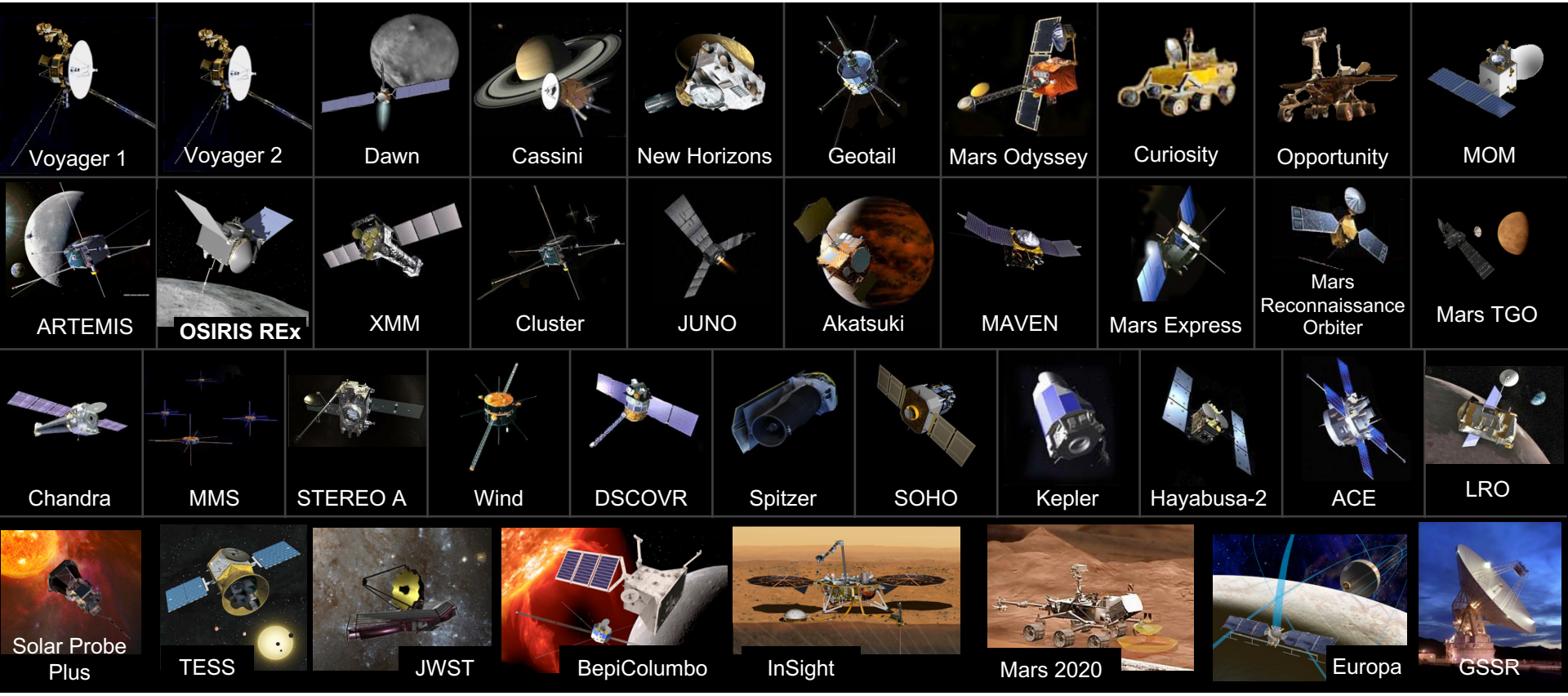
Missions Supported by the DSN



NASA Deep Space Network

GDSCC Goldstone, CA USA

DSS-24 BWG-1 | DSS-25 BWG-2 | DSS-26 BWG-3 | DSS-23 BWG-4

Signal Processing Center SPC-10

DSS-14 70m

DSS-13 BWG Test Facility

MDSCC Madrid Spain

DSS-54 BWG-1 | DSS-55 BWG-2 | DSS-56 BWG-3 | DSS-53 BWG-4

Signal Processing Center SPC-60

DSS-63 70m

DSS-65 HEF

CDSCC Canberra Australia

DSS-34 BWG-1 | DSS-35 BWG-2 | DSS-36 BWG-3 | DSS-33 BWG-4

Signal Processing Center SPC-40

DSS-43 70m

New Antennas Not Completed Yet

80-kW BWG | 20-kW BWG

- 70m antennas (3)
- 34m antennas (9)
  - New antennas DSS-56 & DSS-53 to be completed in 2020. DSS-65 to be retired.
  - DSS-23 will be completed in 2024, with optical capability added in 2025.
  - A second RF-optical hybrid is planned for 2026.

Optical Communications in the Deep Space Network (DSN)

- The DSN has currently 12 operational (RF) antennas in three Deep Space Communication Complexes (DSCC)
  - RF DSN equipment covers L-, S-, X-, K-, and Ka-bands
  - The DSN can support both deep space and near-Earth bands. Some frequencies can be used for radio astronomy and radar science.
- The DSN supports 35-45 missions, plus some radio and radar science
- DSN scheduling processes match mission needs to antenna availability
- The scheduling of NASA's deep space antennas to meet the communications and tracking needs of 40+ missions can be extremely complex
  - Spacecraft locations often depend on relative positions of Earth and other planetary bodies and the geometries often do not repeat
  - Critical events such as launches, orbit insertions, planetary encounters, and planetary landings receive extra DSN resources and priority
  - Also, DSN schedulers need to factor in maintenance activities when DSN antennas are unavailable
- The DSN is now developing a new hybrid RF and optical antenna, capable of doing both RF and optical spacecraft passes with the same aperture
  - Adds an 8m optical segmented-mirror aperture in the central portion of a 34m RF antenna
- The addition of optical communications to the DSN will result in <u>many</u> changes to the way that the DSN and the supported space missions operate

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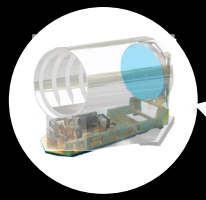
DSN Hybrid RF-Optical Antenna Concept

- Inexpensive, small, actuated spherical glass mirrors synthesize 8m optical aperture inside DSN 34m antenna
  - Fast steering mirror & photon counting optical detector at apex
- Simultaneous RF and optical comm (~ 0.6 dB RF link loss)
- Array two DSN 8m optical apertures to get 11.3m aperture
- Can get > 500 Mbps from Mars, X100 more than X-band
  - Meets Human Exploration 230 Mbps Mars requirement
- FY19 work includes start of 7-element DSS-13 prototype
- 7-element RF-Optical prototype complete 2021
- 4.1m equivalent aperture 2023
- 8m aperture 2025

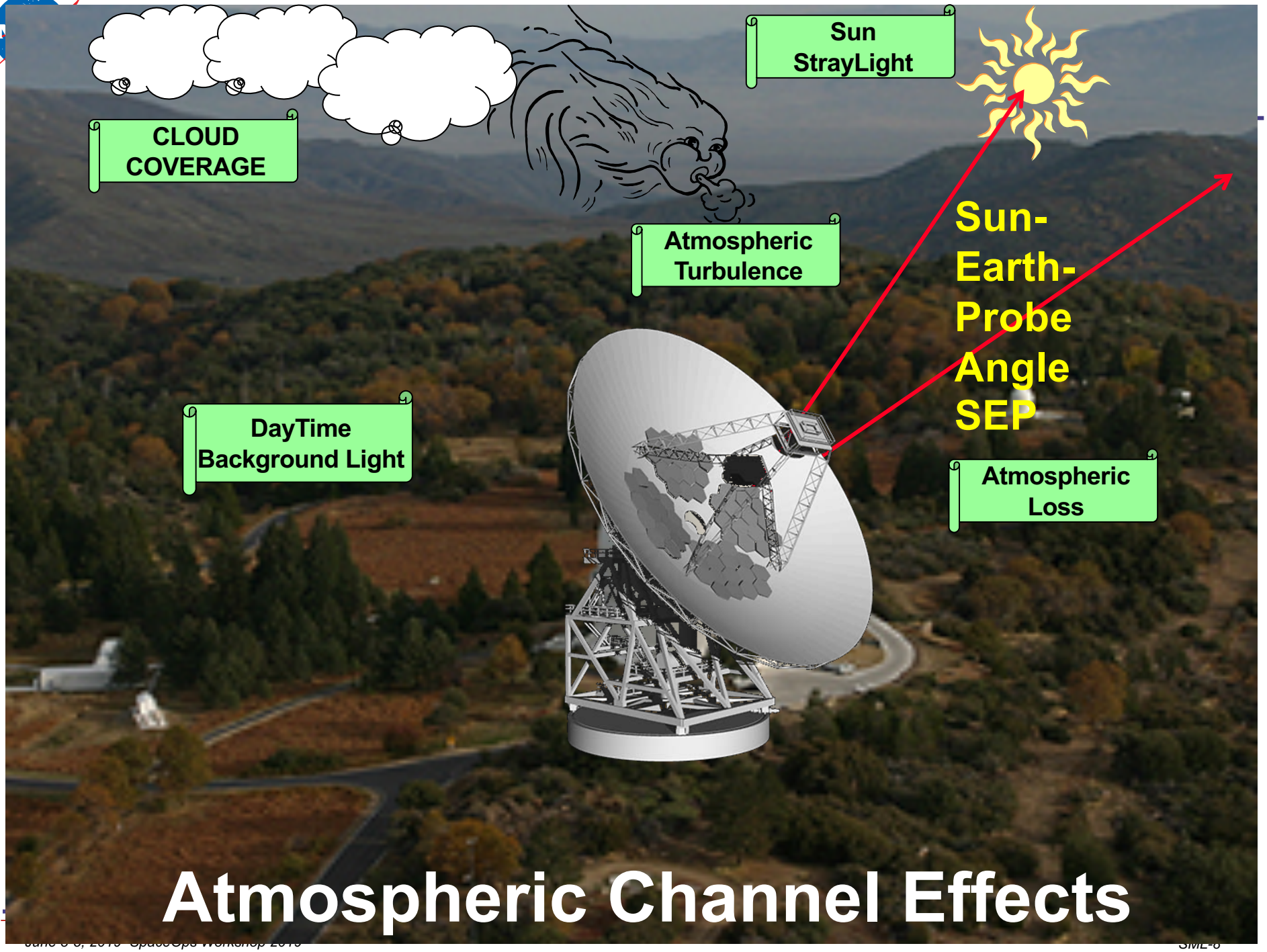
Deep Space Optical Comm (DSOC) Terminal on NASA's Discovery mission Psyche -- 2022 launch. Palomar Obs. will be rented for short flight demo.



First DSN Hybrid RF-Optical antenna leverages existing DSN infrastructure at 1/2 to 1/3 cost of standalone optical ground terminals. Available 2023-2025 for Psyche & Human Space Flight missions best efforts coverage; operational in 2025.

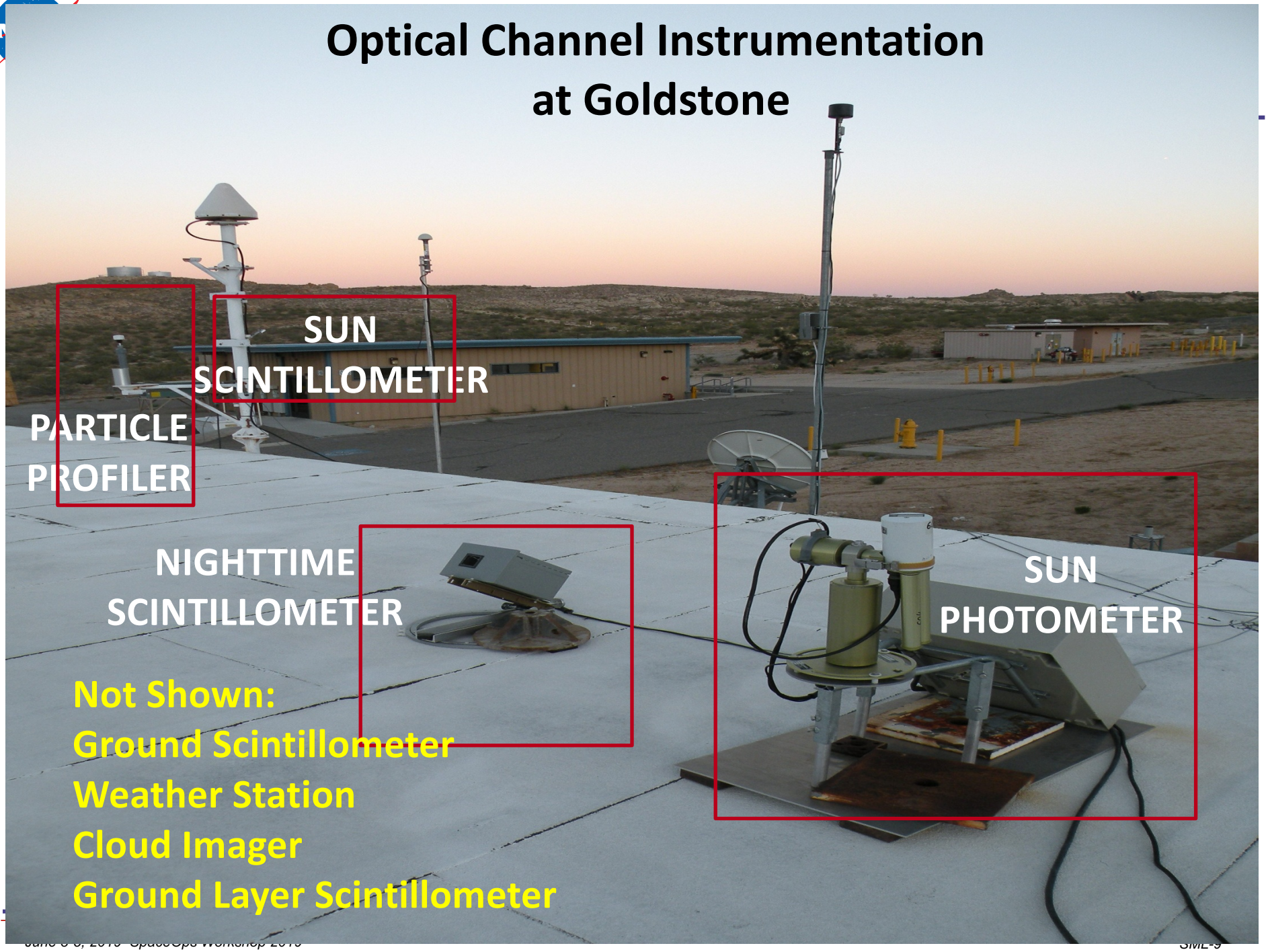
Optical Communications – Site Assessments

- DSN's first optical/hybrid antenna is underway at Goldstone, CA (DSS-23)
  - Lowest cost approach is to deploy second optical antenna at an existing DSN site due to infrastructure and experienced Operations/Maintenance teams in place
  - Potential optical sites need assessment for sky and atmospheric conditions, seeing, clouds, weather etc.
- If second 8m optical aperture is also located at Goldstone, the two can be arrayed to create equivalent of 11.3m optical aperture
  - Alternatively, location at a distant site would add geographic diversity, also desirable
- Site evaluations
  - Require instrumentation and sensors and multi-year campaign, as JPL has done at Goldstone and other southwest U.S. sites
  - Trades to balance the physics (atmosphere) and economics for candidate sites

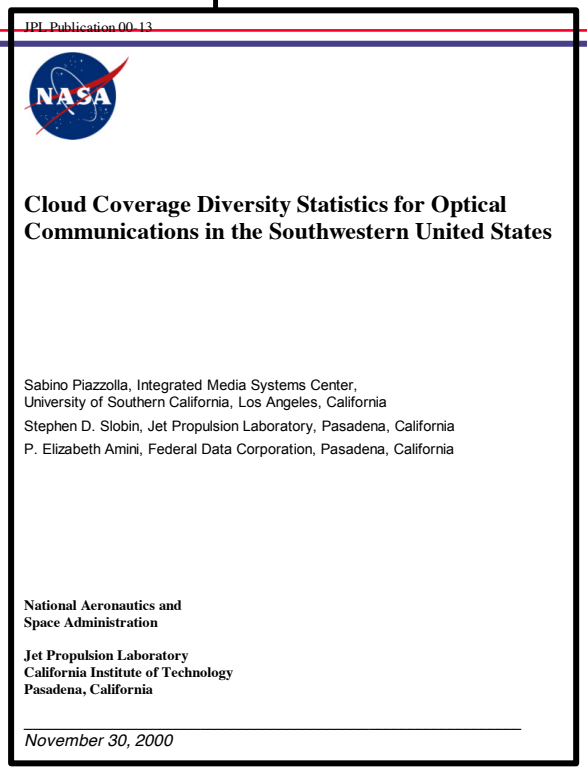


Atmospheric Channel Effects

Optical Channel Instrumentation at Goldstone



Optical Communications – Site Assessments



IPL Publication 00-13

Cloud Coverage Diversity Statistics for Optical Communications in the Southwestern United States

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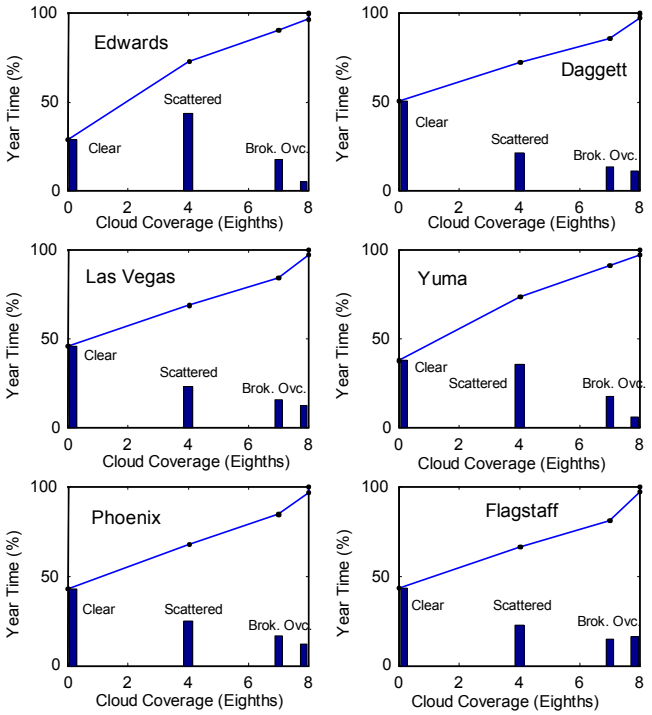
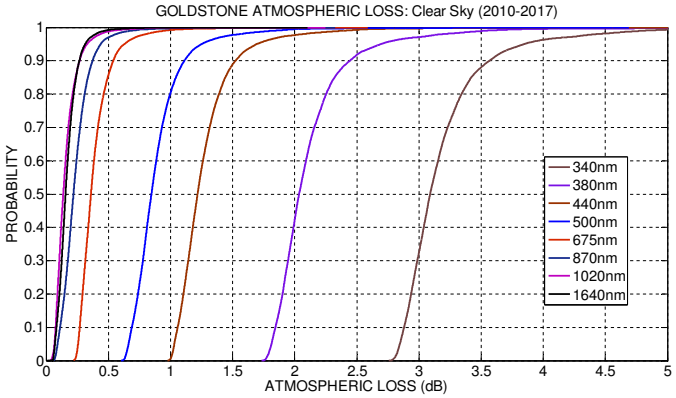


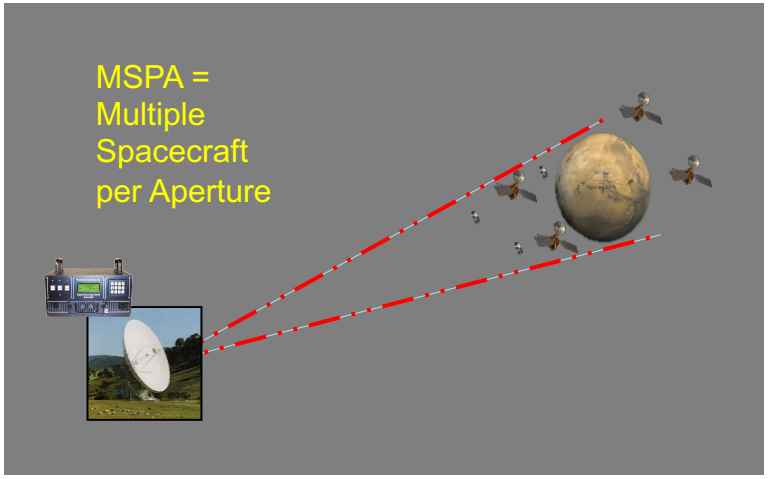
Fig. 4.2 **a)** Average cloud coverage statistics for six of the ten observation sites. The piece-wise cumulative distribution curve and the bar chart for the condition of clear, scattered, broken, and overcast are both shown in each plot. The vertical segment between the two dots at eight/eighths is the measure of the missing data.



From FY18 DSN RF-Optical Hybrid Studies Final Report, showing analysis of Goldstone optical seeing quality

DSN Era of Optical Communications Will Bring Many Changes

- The new DSN capability to receive RF and optical signals will result in many changes to DSN operations, mission planning, and mission operations:
  - Optical data rates > 500 Mbps from Mars require upgrades of network/infrastructure elements
  - New optical compatibility test equipment, facilities, and procedures
  - DSN maintenance procedures will change with the new optical hardware
  - Minimum angular separation between the spacecraft and Sun will be different for RF and optical links, affecting both scheduling and operations
  - New cost models will be needed for DSN aperture time with optical
- The DSN MSPA and FtSO processes will require updating for RF + optical



FtSO = Follow the Sun Operations. DSN operations are highly automated under FtSO. The site in daytime remotely controls and operates all three DSN sites

DSN Era of Optical Communications: Many Changes (cont.)

- DSN antenna scheduling and loading tools and processes will need to be majorly modified when both RF and optical communications are used
  - Current practice is for a conflict-free DSN tracking schedule to be produced 12-16 weeks before real time. Some tweaks to that conflict-free schedule are often made leading up to real-time.
  - Missions using optical may need to plan for different flight system behaviors in order to ensure correct pointing for closing the optical link with the DSN
  - Optical scheduling will need to factor in automated, near-real time sky, cloud & weather sensing and forecasting to detect clouds or weather that compromise or preclude optical communications
  - Response will need to be immediate and automated. Motorized segmented mirror covers will need to automatically cover and protect the optical elements under certain environmental conditions.
  - Options when optical communications is not possible due to sky, clouds or weather
    - Cancel and reschedule the pass. Or, use RF downlink, albeit with lower data rate/volume. This will require automated DSN schedule changes to accommodate the repurposing of DSN equipment.
    - If a mission uses a lower rate RF downlink when an optical pass is unavailable, it will need to plan for how or when to downlink the rest of their data. Scheduling updates in real-time will be required. There will be implications for onboard storage. Missions and DSN will need to plan and coordinate closely.
  - "Downtime" and antenna maintenance periods are currently a major factor in DSN scheduling. The addition of optical mirrors to the DSN antennas will bring in new maintenance processes and new challenges for scheduling DSN assets for space mission services.